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Report No. FAA-RD-78-94

LIGHTING & MARKING OF EXIT TAXIWAYS

Charles A. Douglas

AUGUST 25, 1978

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16. Abstract

The problem of lighting exit taxiways has been a long standing one. In an effort to resolve it, an investigation was made of the feasibility of emphasizing the visibility of the throat of an exit taxiway by means of special lights. The investigation consisted of a review and analysis of the literature.

The use of green lights installed in the runway surface on the extended taxiway centerline marking is in common use for lighting both high-speed and low-speed exits. This method has not been adopted in the United States because of concern over the possibility of mistaking a low-speed exit for a high-speed exit. Tests to determine if this concern is valid are recommended.

A system of pulsating blue lights at the entrance to the throat shows promise. Tests of this system are recommended.

Modifying the type L-829 signs located at exits from the runway to increase their conspicuity, improved shielding of taxiway edge lights, use of asymmetric instead of symmetric lenses on straight stretches, dimming of taxiway edge lights would improve the guidance and reduce the "sea-of-blue" effect. Tests of these modifications are recommended.

The use of high-efficiency retroreflective paint to mark the turn-offs to the exit taxiway will improve nighttime guide and is recommended.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

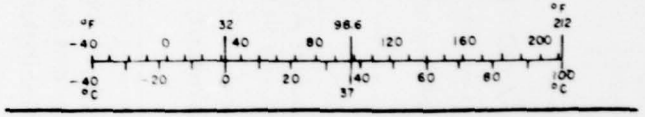

TABLE OF CONTENTS

LIST OF FIGURES

ABBREVIATIONS

CAA	Civil Aeronautics Authority (or Administration), Washington, D. C. (Superseded by FAA)
FAA	Federal Aviation Administration (or Authority), Washington, D.C.
ICAO	International Civil Aviation Organization, 1000 Sherbrooke, Montreal, P.Q., Canada
IES	Illuminating Engineering Society, 345 E 47th St., New York, New York
NAFEC	National Aviation Facilities Experimental Center
RAE	Royal Aircraft Establishment, Farnborough, Hants, England
VAP	Visual Aids Panel

LIGHTING AND MARKING OF EXIT TAXIWAYS

1. INTRODUCTION

1.1 Scope

This report gives the results of a study of the feasibility of emphasizing the visibility of the exit taxiway throat by special lighting conducted as part of Interagency Agreement DOT FA77 WAI-786 with the Naval Air Engineering Center, Lakehurst, New Jersey. The study was performed by Quanta Systems Corporation, Rockville, Maryland, under Contract N68335-78-C-2022, and consisted of a review of the literature, an analysis of the feasibility of using flashing dual blue edge lights and of the feasibility of using "wig-wag" lights, and a review of the literature reporting the results of studies of other efforts to improve the recognition of exit taxiway throats at night.

Taxiway lighting is the least publicized of the airport lighting systems. The need for taxiway lighting developed rather slowly; with minor modifications, runway edge lights could be used as taxiway edge lights, and there were no substantial differences of opinion as to what was required. Hence, there have been few publications which are related specifically to the problems of the design of taxiway lighting systems. For example, the Aviation Committee of the Illuminating Engineering Society was deeply involved in the development of aviation ground lighting systems during the period 1930 to 1950. Although minutes of its meetings and conferences during that period are replete with references to beacons, obstruction lights, approach lights and runway edge lights (then referred to as contact lights) during that period, the first mention of taxiway lights is in the minutes of its 23rd meeting, November 4 & 5, 1946.

The feasibility of a system proposed for emphasizing the visibility of exit taxiways can be judged only in the context of previous experience and current practice.* Hence, a comprehensive review was made of the literature relating to the lighting and marking of exit taxiways. An analysis was made of the methods proposed for increasing the conspicuity of exit taxiway throats, and recommendations based upon this analysis were formulated.

1.2 Historical Background of the Development of the Present Visual Aids for Taxiing

In the 1930's when paved runways and runway-edge lights were becoming common, the runways themselves were available for most of the taxiing because traffic was light. Taxiways were usually short, leading from the apron directly to the runway as shown in figure 1.

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* "Those who cannot remember the past are condemned to repeat it." George Santayana: Life of Reason I.

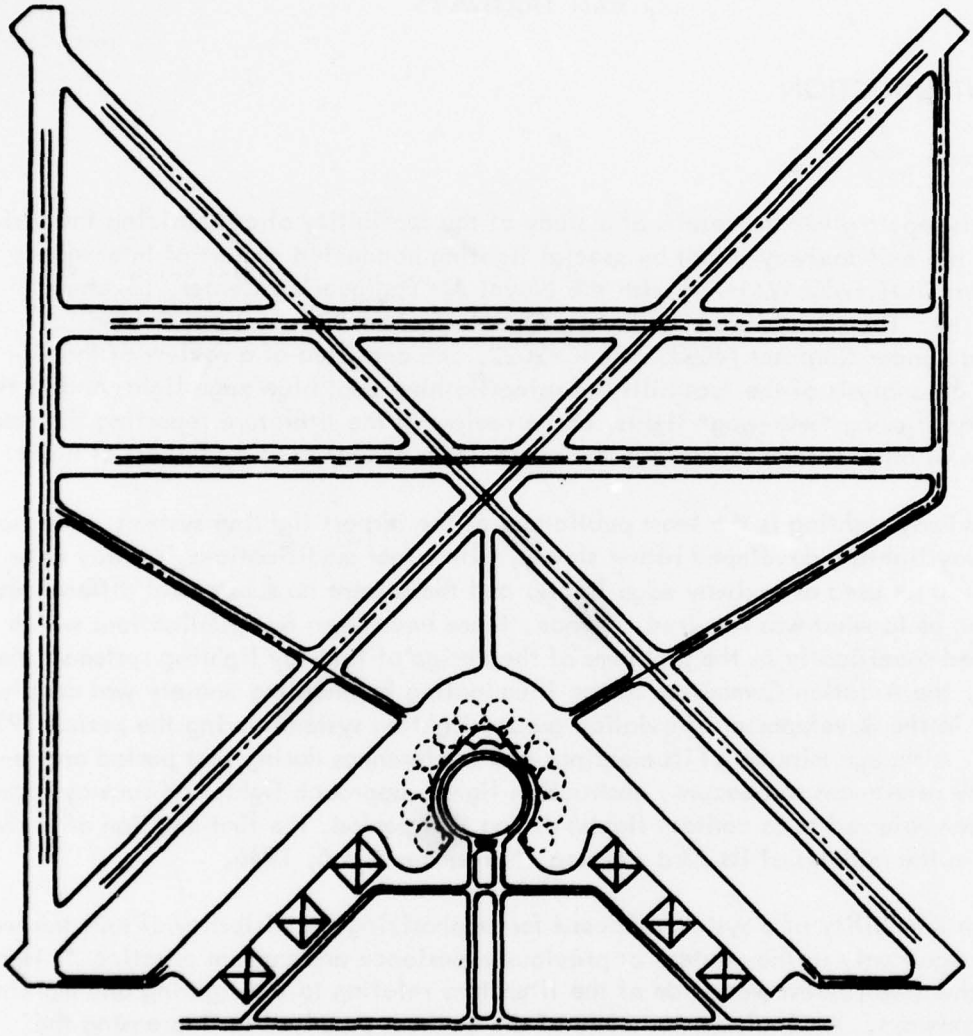


Figure 1: - Plan of a representative airport illustrating the simple taxiway systems of the 1930's and early 1940's.

In those days airports were usually floodlighted, and this lighting, plus the landing light(s) on the aircraft, provided sufficient guidance for taxiing. In addition, no lights on the airfield were permitted to project more than three inches above the surface of the ground. Hence, installation of a taxiway system, consisting of semi-flush lights, would be costly, thereby delaying the installation of these lights.

A search of the literature did not yield a firm date for the beginning of the use of taxiway lights. Breckenridge, in his 1937 paper "The Airport Lighting Specifications of the Department of Commerce", [1] makes no mention of taxiway lights. Moreover, figure 3 of that peper shows no chromaticity requirements for the color "blue". Similarly, British Standard Specification for "Land Aerodrome and Airway Lighting" of June 1937 does not mention taxiway lighting nor specify the characteristics of "blue" [2]. In addition, Civil Aeronautics Bulletin No. 10, "Airport Lighting" of September 1, 1938, does not list taxiway lights [3]. Hence, we can conclude that these lights were not used to any extent before 1938.

However, Specification AN-C-56 "Army-Navy Specification for Colors: Aeronautical Lights and Lighting Equipment", dated July 25, 1942, does specify the chromaticity requirements for "blue" but does not list taxiway lights in its table III, which gives the color temperature of the illuminants of various airport lights [4]. This omission is not very significant, as in those days taxiway lights were simply contact lights to which a blue filter had been added.

The book "The Federal Airways System", published by the IEEE (1970), states that practically no taxiway lighting as used today was installed prior to 1940 and that in 1941 the Army-Navy-Civil Committee (ANC) was established by the Munitions Board [5]. This committee established a standardized code for color signals and called for blue for taxiway lights. No date for this standardization is given.

1.2.1 Marking of Exit Taxiways

Early specifications for the marking of runway-taxiway intersections required that "Where taxiways intersect runways, the centerline taxiway stripe be continued onto the runway to the stripes placed along the center section of the runway" [6]. (See figure 1) It should be noted that reference 6 specified that the paint used for taxiway parkings be a yellow retroreflective paint composed of a pigmented binder with minute glass spheres embedded in the binder.

However, this marking was soon found to be inadequate even for the aircraft of the 1940's. At runway-taxiway intersections intended for use as exits, the straight-in taxiway centerline markings was changed to a marking curved to meet the runway centerline marking as shown in figure 2 [7]. A similar pattern was being used in the United Kingdom in 1947 [8].

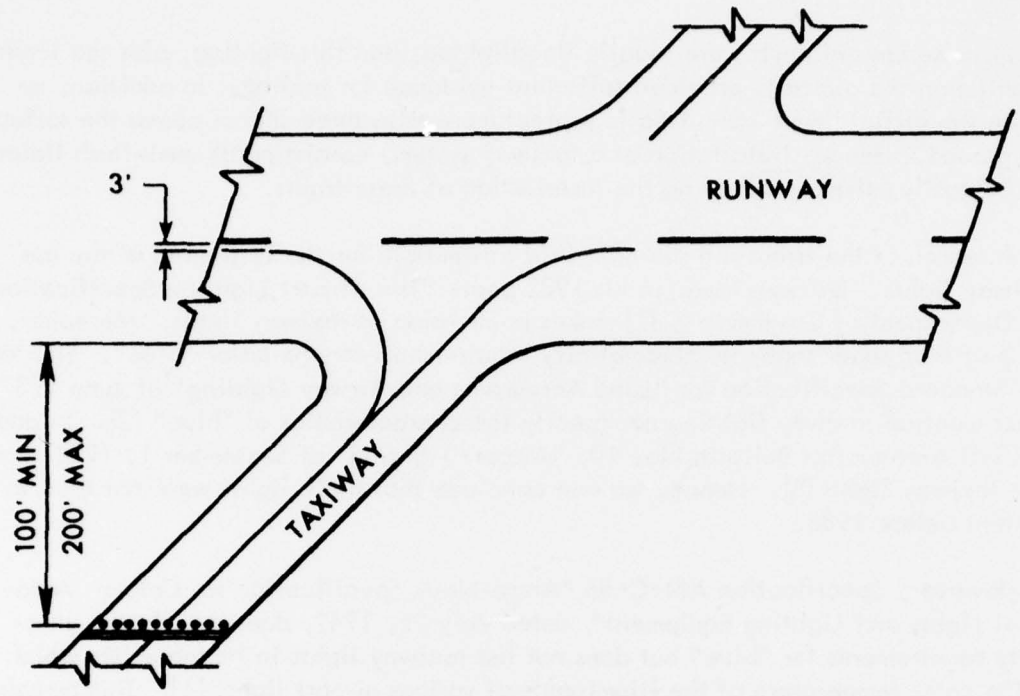


Figure 2: - Curved extension of taxiway centerline onto runway specified in 1953 [7].

This marking pattern is still used both nationally [9] and internationally [10 (section 5.2.8)].

The need for exit taxiway markings is demonstrated by the flight tests in fog at the Landing Aids Experiment Station, where the taxiway markings did not extend onto the runway. As a result of the problems encountered during flight tests conducted in visibilities as low as 300 feet, the Landing Aids Experiment Station recommended that "taxiway markings be devised and standardized to give a pre-warning of turns and intersections" [11].

1.2.2 Lighting of Exit Taxiways

The inclusion of a specification of the chromaticity boundaries for blue light in Specification AN-C-56 [4] indicates that the choice of the color blue for taxiway edge lights was made in the period 1940-41. Calvert states that the color blue was chosen during World War II because it gave the best security against the operation of intruder

aircraft [8]. However, a more likely reason, at least in the United States, is that blue was the only recognizable color not being used on airports. The human eye can recognize only four, or at the most five, colors of lights which appear as point sources; red, green, blue, and white/yellow. The colors white and yellow can be differentiated from each other only when seen in close proximity in time and space, as with adjacent lights or alternately flashing lights. At the time the color blue was chosen, red was being used for obstruction lights and for some approach lights; green was being used for threshold lights and range lights, and white and yellow were being used for contact (runway edge) lights, leaving only the color blue available for the taxiway edge lights.

Obtaining a satisfactory blue color with a light using an incandescent lamp as a source, requires that a glass lens or filter have a transmittance of 0.02 or less, a transmittance which is only one-tenth that of a red or green lens or filter. Hence, blue is the least desirable of colors insofar as intensity is of concern. However, the intensity requirements of taxiway-edge lights are not as severe as are the intensity requirements of runway end, threshold, and edge lights, and taxiway lights of satisfactory intensity could be obtained by adding blue filters to clear runway edge lights.

Semiflush lights, type AN-L-9, were to be used except that for snow areas the use of snow area lights were suggested. Lenses producing asymmetrical beams were to be used on straight portions of the taxiway, and lenses producing symmetrical beams were to be used on exits, entrances, and curves [12].

Very early in the development of taxiway lighting two blue lights spaced five feet apart, known as entrance-exit lights, were placed on either side of a taxiway at an intersection with a runway provided such intersection was to be used as an entrance or an exit, as shown in figure 3 [13]. (One wonders how many pilots were aware that an intersection was not to be used as an exit if it was not marked by entrance-exit lights!)

The use of these entrance-exit lights continued for many years with no evaluation of their effectiveness. Then in 1962, Simeroth in a study made at the National Bureau of Standards Visual Landing Aids Field Laboratory, recognizing the ineffectiveness of these lights, recommended that their use be discontinued and that the light removed from the entrance-exit configuration be placed elsewhere along the edge of the taxiway; for example, at the point of tangency of the edge of the exit taxiway with the edge of the continuing straight section [14]. After some delay, Simeroth's recommendation was adopted and entrance-exit lights are no longer specified for runway exits which are not marked with entrance-exit signs [15, 16].

Because of the high cost of installing semi-flush taxiway edge lights, retro-reflective delineators were often used instead of lights during the 1940's. The Air Corps specified the use of such delineators, not lights, in 1944 [6] and continued using delineators into the 1950's. The carrier-based Navy aircraft of the period did not have

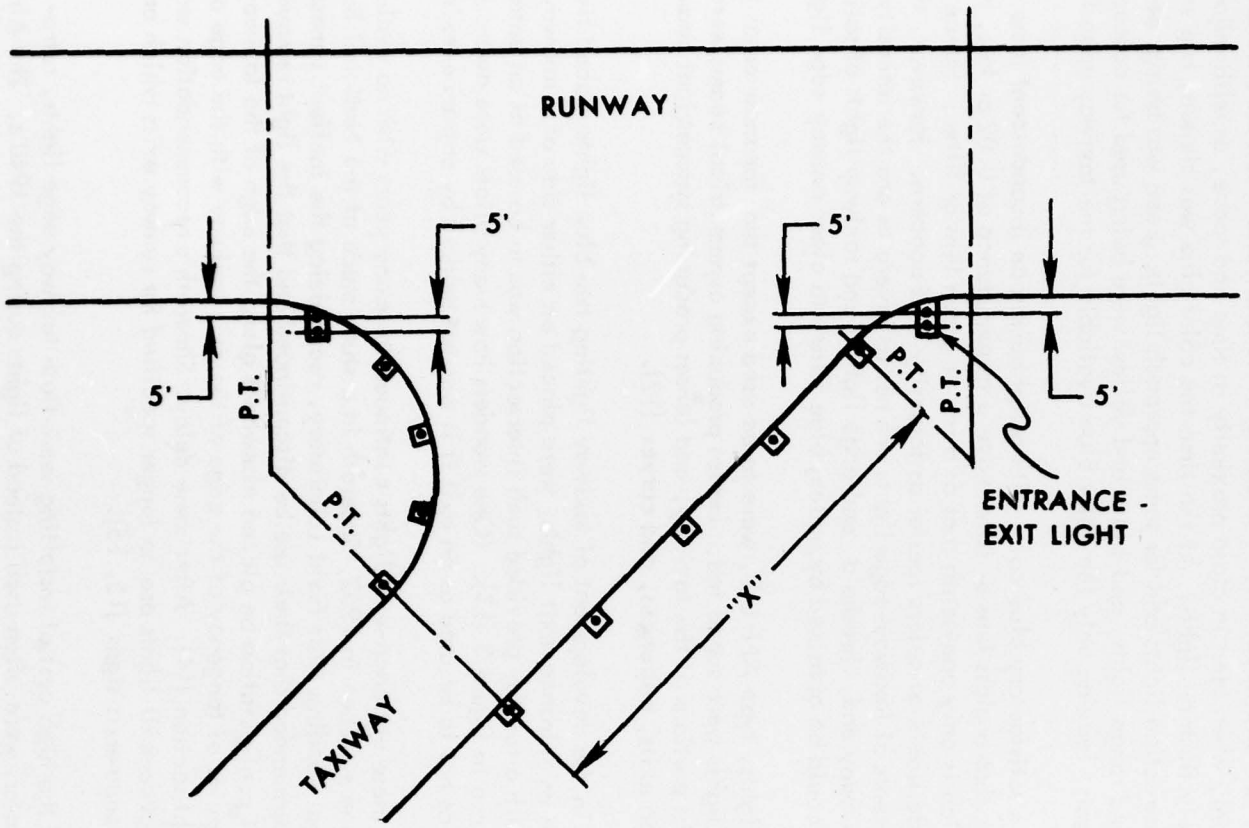


Figure 3: - Entrance-exit lights at exit taxiway.

landing lights. Hence, the Navy, in permitting the use of delineators, stated that the system was "suitable for aircraft which have a light source in the vicinity of the cockpit," with the qualification that "In all instances a flashlight, or other light directed at the reflectors by the pilot will provide better visibility . . . ." The use of delineators spaced five feet apart for use as entrance-exit lights was specified [12].

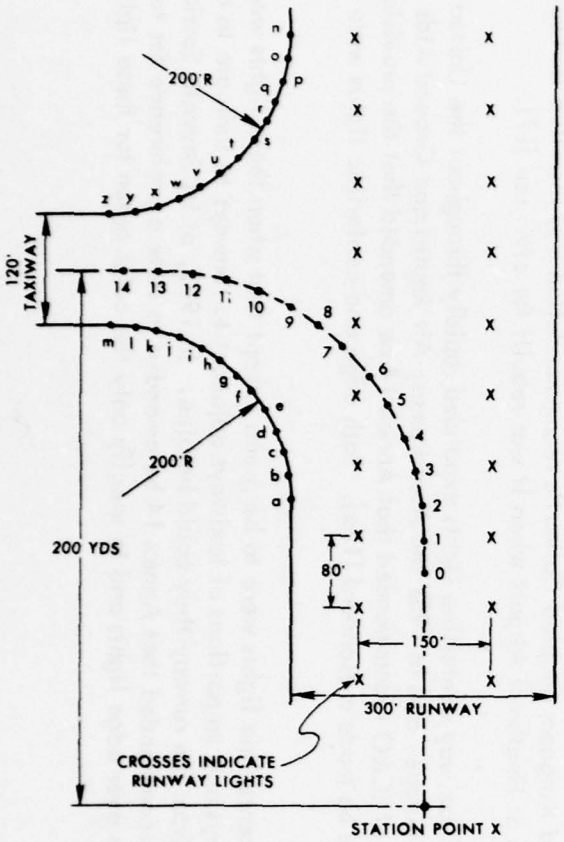
Upon the conclusion of World War II, Calvert conducted a study of the problems of providing taxiway guidance with emphasis on its application to large civil airports during periods of low visibility. Lighting of taxiway exits received particular attention [8]. From his analysis of the problems resulting from the installation of runways and taxiways wider than those used during the war, he concluded that, "The pilot of an aircraft taxiing on a large aerodrome with wide featureless runways and taxiways is in a somewhat similar position to a fly crawling on a blackboard. In good visibility he can see the edges of the runways and taxiways, and can obtain aiming points by noting where these vanish on the horizon. As the visibility gets worse, the edges become indistinct, all distant aiming points are blotted out, and the pilot is reduced to following lines, just as a motorist in a fog follows a kerb."

Using a series of figures similar to those shown on figure 4, he concluded (in 1946!) that the best hope of providing the desired guidance was by means of lights on the taxiway centerline instead of at the edges. At runway-taxiway intersections the lights were to be extended to the runway centerline in the same way that the markings were (See Figure 4). Calvert proposed that the color of the centerline lights be green instead of blue in order to conserve power and to differentiate them from blue taxiway edge lights. Since the colors white and yellow were used for runway edge lights and red was reserved to denote danger, the use of green was preferable to these colors even though green was also used for threshold, and at that time runway-end, lights.

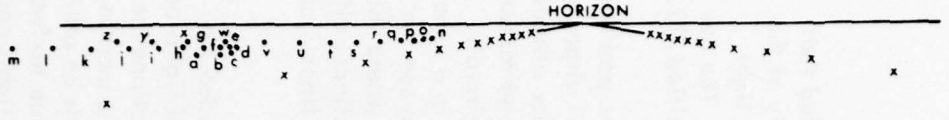
The United Kingdom adopted Calvert's recommendation and installed taxiway centerline lights at Heathrow Airport when it was rebuilt for civil use [17].

The use of taxiway centerline lights expanded rapidly throughout the United Kingdom and in Europe, and in 1957 the Aerodromes, Air Routes and Ground Aids (AGA) Division of ICAO recommended that Annex 14 be amended that the provision of taxiway lights be made a Standard [17a]. Both edge and centerline lights were listed as permissible.

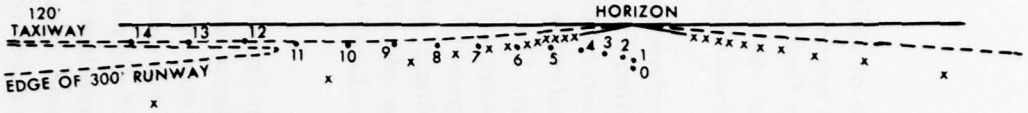
Taxiway centerline lights were to be green except that when these lights were installed on runways and on portions of taxiways adjacent to runways to indicate to a pilot his turn into or from the runway they could be blue. In 1962, at its Seventh Session, the AGA Division recommended that Annex 14 be amended to state a preference for taxiway centerline lights over edge lights and to specify only the color green for these lights [18].



4a. Locations and identification of the lights shown in b and c.



4b. Perspective view of exit taxiway edge lights as seen from Station X.



4c. Perspective view of exit taxiway centerline lights as seen from Station X.

X Runway edge lights
● Taxiway lights

NOTE 1: Pilot is 12 feet above runway.
NOTE 2: To obtain a realistic impression from figures 4b and 4c, they should be held at a distance of 8½ inches in front of one eye with the other eye closed.

Figure 4. Examples of Perspective Diagrams used by Calvert [8].

2. THE PROBLEM

Lighting the exit taxiway has been a problem since taxiway lights first came into use, and no completely adequate solution has been found when lights, or signs, are installed only at the edges of the exit taxiways. It is difficult for one to recognize the problem from a plan view of a runway-taxiway layout of the type shown in figure 5. However, consider the situation for a pilot, in an aircraft having an eye-to wheel height of 15 feet, located over the point marked X on the runway. All lights above the line AB will be viewed within a region extending from 0.4° below the horizon to 1.7° below the horizon, an angular band narrower than that subtended by the width of a finger viewed at arms length. The taxiway lights truly are seen as a "confused jumble of lights" [19]. See figure 6. The pilot can neither determine the precise location of the exit taxiway nor the angle at which it intersects the runway at the distances required. By the time he gets sufficiently close to recognize the pattern of lights in the exit taxiway, it is often too late for him to execute the exit smoothly. It is apparent that guidance is needed in addition to knowledge of the location of the exit.

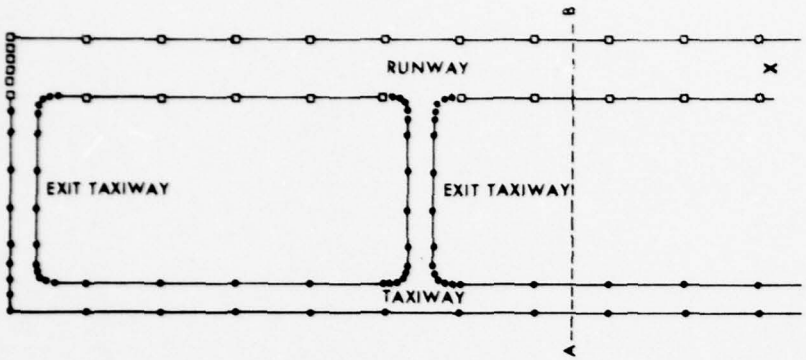
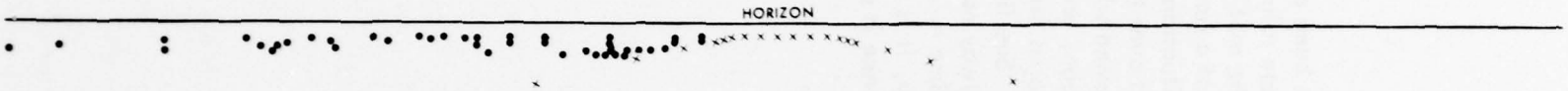


Figure 5. - Plan view of representative arrangement of runway and taxiway edge lights.



NOTE: To obtain a realistic impression from the figure, it should be held at a distance of $8\frac{1}{2}$ inches in front of one eye with the other eye closed.

Figure 6. Perspective View of the Lights Shown in figure 5 as seen from a Position 15 feet Above the Point X of figure 5.

3. EFFORTS TO IMPROVE THE LIGHTING OF EXIT TAXIWAYS

3.1 Use of Specially Shaped Taxiway Lights

The Landing Aids Experiment Station found that taxiway edge lights were not adequate to mark runway-taxiway intersections in 1/8-mile day and night visibility conditions and recommended that tests be made of "horizontal linear light sources" [11].

In 1947 the Technical Development Service of the Civil Aeronautics Administration developed an elevated gaseous discharge taxiway marker light as a replacement for the type AN-L-9 semi-flush lights. This light, shown in figure 7, was designed to "indicate the exact location of the taxiway without the pilot being required to see more than one light at a time" [20].

Lights of this type were installed at several large civil airports, and at the Landing Aids Experiment Station. They never came into general use, presumably because of their cost, the requirement for a multiple power supply, and the effects of prop wash and jet blast.

3.2. Reducing Number of Visible Lights

3.2.1 Shielding

Shielding the taxiway edge lights to reduce the light emitted in directions away from the taxiways is used, but not consistently, on taxiways. Such shielding, at best, can cut the number of lights in the "sea-of-blue" to half their former number.

A better engineering approach to the design of shielded lights is required. This approach should include the following:

a. The use of asymmetrical instead of symmetrical taxiway lights on straight sections to increase the ratio of the intensity of the light emitted in the directions in which it is needed to the intensity in the directions where it is not needed.

b. Greater restriction of the intensity of the light emitted toward the taxiway in directions within the angular region $\pm 75^{\circ}$ to the perpendicular to the taxiway centerline. A pilot using these lights views them only at short distances at angles within this region and, therefore, very low intensities are required. For example, a light viewed at 0° (right angles to the centerline) from an aircraft over the taxiway centerline requires only 0.01 candela in 300-foot RVR meteorological conditions to be easily seen at night. The range of a light of this intensity in very clear weather

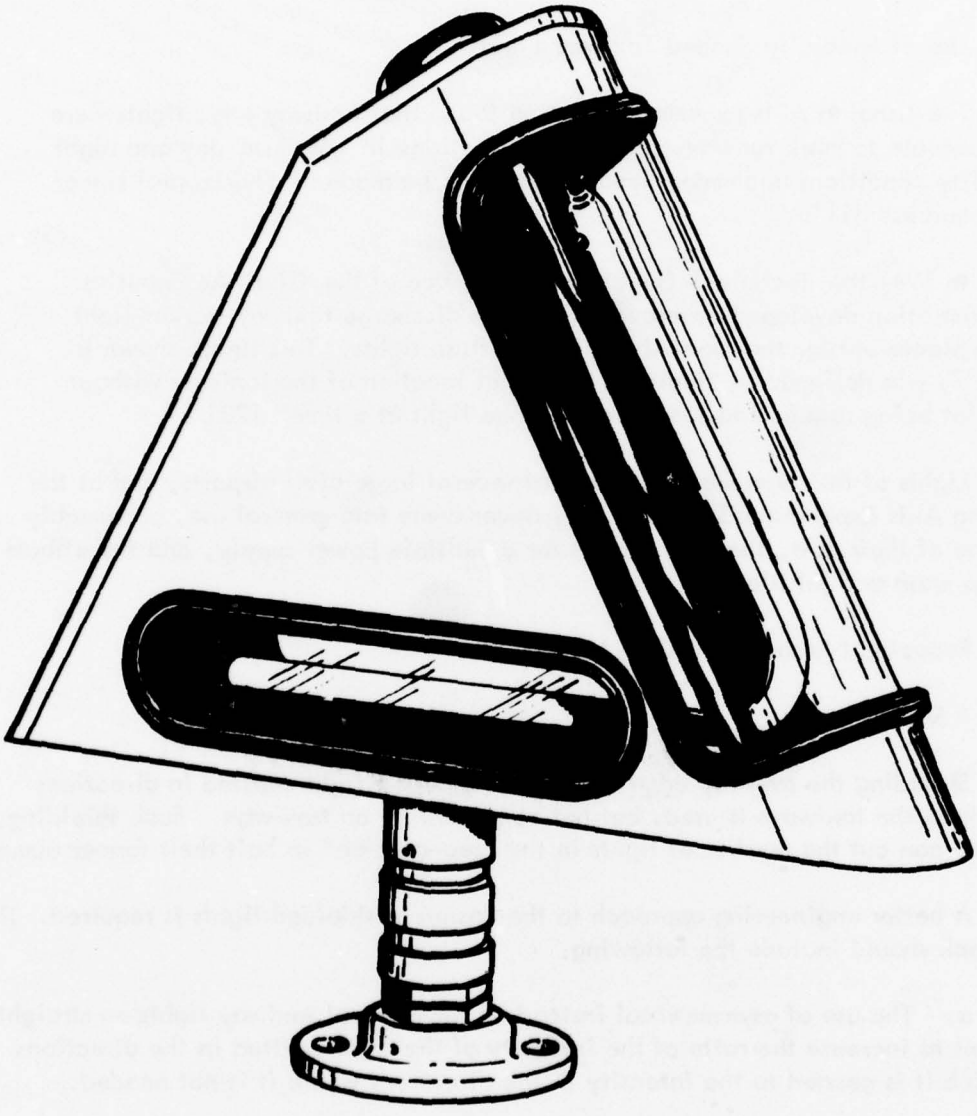


Figure 7: - Gaseous Tube Taxiway Marker Light

is approximately 400 feet. Similarly, an intensity of approximately 0.1 candela is adequate at $\pm 60^{\circ}$. The range of a light of this intensity in very clear weather is approximately 1200 feet. The angles and intensities given above are applicable only to straight sections of taxiways. Curves and exit taxiways will require special attention which is beyond the scope of this report.

c. Dimming of the taxiway lighting system in clear weather. This will reduce the glare on the taxiway and decrease the visibility of the lights from unwanted directions.

d. Sectionalizing taxiway lighting circuits to turn off unneeded lights.

e. Use of retroreflectors to delineate taxiway edges as supplement centerline lights instead of blue taxiway-edge lights.

3.2.2 Reducing Number of Extraneous Taxiway Lights

The sea-of-blue effect can be reduced by using semi-flush centerline lights instead of elevated edge lights, since the semi-flush lights will usually be obscured in the off-taxiway directions by the terrain, if the taxiway edges are delineated by retroreflectors instead of elevated lights.

The number of energized taxiway lights can, in some instances, be significantly reduced by sectionalizing the power circuits so that only the lights on taxiways serving the duty runway need be energized.

3.3 Taxi Guidance Signs

As airports become larger and more complex and as air traffic became more congested in the years following World War II, the need arose for more routing and destination guidance than could be given by oral communication from the control tower. To meet this need, the Technical Development Center of the CAA developed an elevated sign for use at taxiway intersections and as a replacement for the double blue entrance-exit lights at runway exits [21]. Signs of this type, now designated as type L-829 and shown in figure 8, have been in use as entrance-exit signs when installed as shown in figure 9 [22].

A bright future was foreseen for these signs. For example, Vipond stated, "Rolling down the flat surface of a runway, a pilot often sees a confused jumble of blue lights off to the side. Perspective plays tricks on him. But there's no mistaking a sign with a brightly lighted arrow and legend" [19]. However, these signs met with almost instantaneous pilot objection; one of the criticisms being the small size of the signs [23].

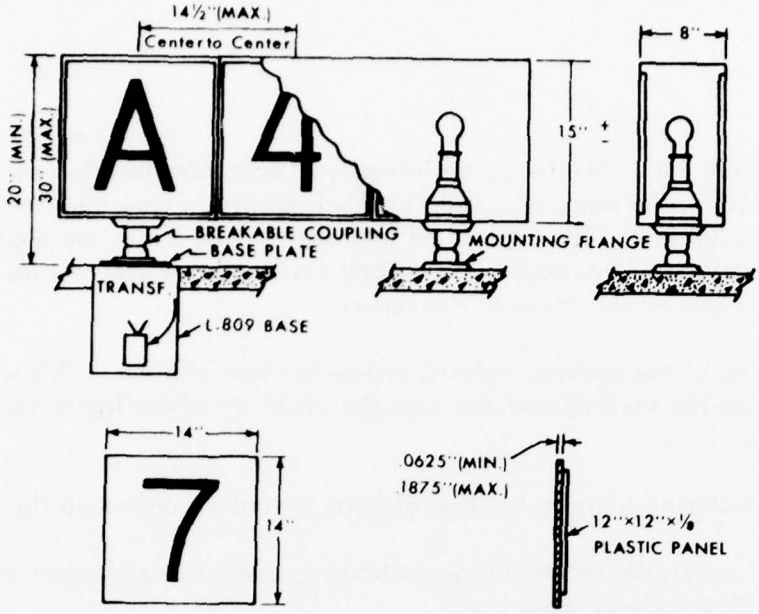


Figure 8: - Type L-829 taxi guidance sign.

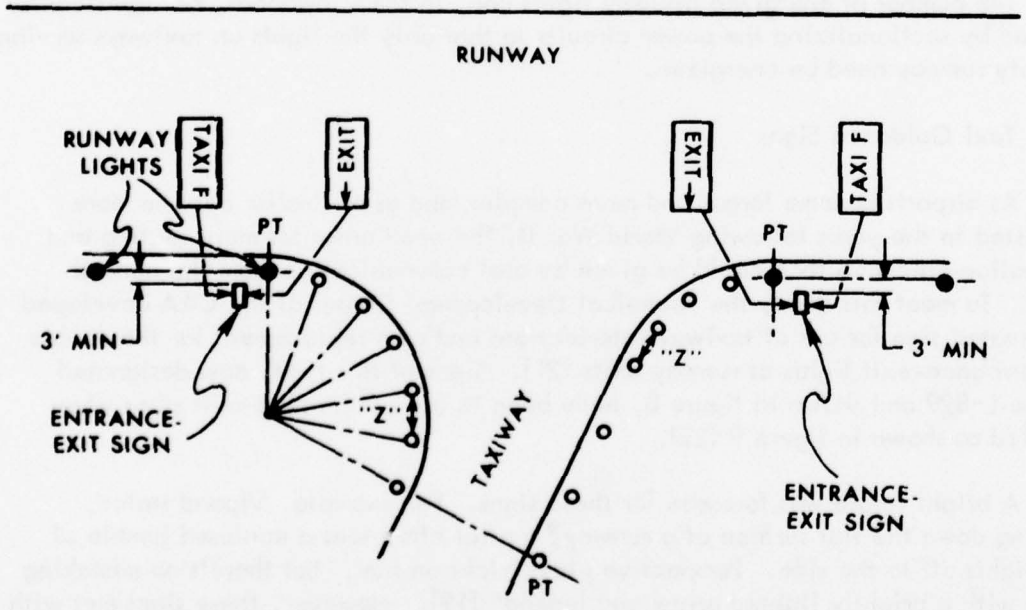


Figure 9: - Location of Entrance-Exit Lights

Larger signs have since been developed and found to be more conspicuous and to have a greater legibility distance than the type L-829 sign [24, 25]. One of these is now designated as type L-858. However, these signs are so large that they cannot be placed sufficiently close to the runway edge to serve as exit locators.

Efforts have been made to obtain large signs sufficiently frangible so that they can be placed close to the runway edge. Inflated signs and "styrofoam" signs have been constructed [26]. However, these signs have been found unsuitable because of complexity, damage from jet blast, and damage to jet engines when pieces of a sign hit by an aircraft are ingested. (No reference describing these tests has been found.)

The type L-829 signs were designed for use both as directional signs and as intersection locators. This duality of purpose required compromises in design which affected their suitability for both uses. Marking the points of tangency of exits required that the signs be low so that they could be mounted close to the edge of the taxiway or runway. This limited their size. These signs were required to be legible a distance of 500 feet. To accomplish this the legends were comprised of lighted letters on a black background and the luminance of the letters was limited to approximately 50 footlamberts [21]. The result was a sign that was of limited conspicuity and legibility.

The conspicuity of the type L-829 sign is inadequate when these signs are seen in conjunction with runway-edge lights operating at the intensities required during periods of low visibility. The conspicuity could be improved considerably if the unnecessary parts of the legends were removed from the signs at exits from runways leaving horizontal bars of yellow light. Thus, the words TAXI and EXIT would be removed from the signs of figure 9. As a second step, the F and the ⟶ would be converted to black on yellow.

It has long been the author's opinion that the use of signs with information regarding destination or taxiway identification along the runway edges is both unnecessary and undesirable, and that the only purpose of signs at exits from the runway should be to mark the location of the exit. For example, the legend RAMP on the signs along runway 18-36 at Washington National Airport conveys no useful information to a pilot who can tell his left hand from his right hand. The conspicuity of the sign is significantly lower than it would be if the legend were removed exposing the lighted panels.

3.4 Use of Special Configurations of Runway or Taxiway Lights

3.4.1 Colored Lights on the Runway Centerline

The use of a single green light installed in the runway centerline was abandoned because of confusion with a green navigation light on an aircraft [27]. The use of a group of such lights on the runway centerline disposed symmetrically about the extended taxiway centerline has been considered [28]. Since such a group of lights could appear as a single light when viewed from a distance, use of this method is not recommended.

It has been recognized that if green lights are to be used on or near the runway centerline to mark an exit, these lights must be in a configuration which cannot appear as a point source at any distance. Thus, the identifying lights should appear as a barette. Such a system is now being tested at NAFEC [29]. However, such an arrangement will not provide as much guidance during a turn off the runway as would the same number of lights installed on the extended centerline of the taxiway.

3.4.2 Configurations Tested at the NBS Visual Landing Aids Field Laboratory

During the period 1958 to 1965, the Visual Landing Aids Field Laboratory of the National Bureau of Standards at Arcata, California, tried several configurations of additional lights installed in the runway or taxiway lighting systems in an effort to obtain a simple, easily installed, low-cost system for marking runway exits [31]. The following methods were tried.

3.4.2.1 High Intensity Beam Directed Across the Runway. Tests were made both in clear weather and restricted visibility. The scattered light provided less information than did reflected light from the runway surface.

3.4.2.2 Closely Spaced Runway-Edge Lights. At one runway exit three additional runway-edge lights spaced at 10 foot intervals were installed in line with the row of runway-edge lights on each side of the exit as shown in figure 10a. At a second exit, three runway-edge lights were installed along both edges of the exit taxiway with their beams aligned parallel to the beams of the runway-edge lights as shown in figure 10b. The extra lights at both exits were energized from the runway lighting circuit.

The closely spaced lights located in line with the runway-edge lights were not adequately differentiated from the rest of the runway lights. The high intensity runway-type lights which were placed along the edges of the exit taxiway were of some value, but the pilot did not receive adequate turn-off guidance until the aircraft was nearly aligned with the taxiway.

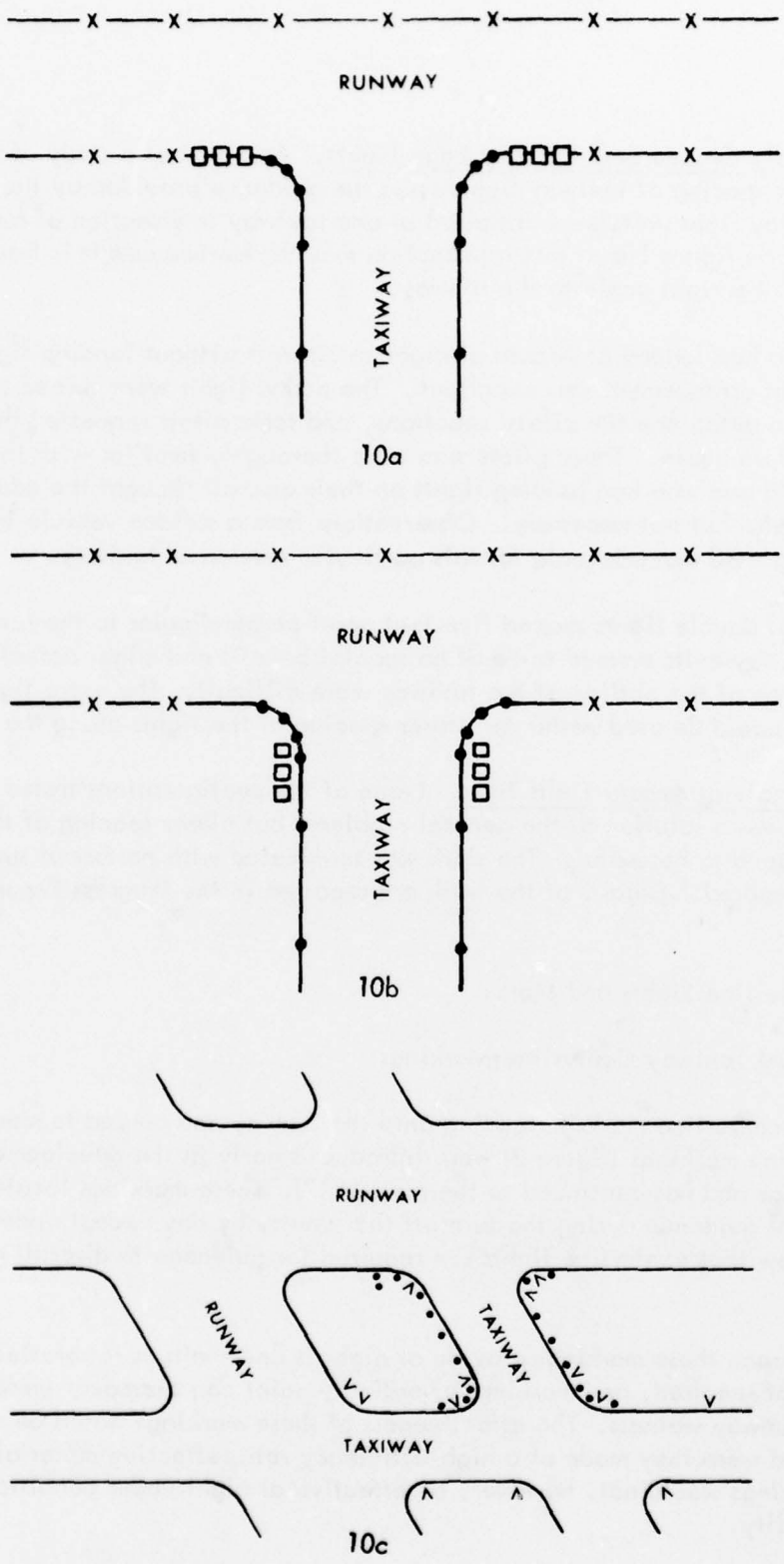


Figure 10: - Configurations of exit lights tested at Arcata.

3.4.2.3 Closely Spaced Exit Taxiway Edge Lights. As a part of a study of the effects of closer spacing of taxiway lights upon the guidance provided by the system, type M-1 taxiway light units were installed at one taxiway intersection of runway 13-31 as shown on figure 10c. This intersection was chosen because it is frequently used and is not at a right angle to the runway.

Pilots who had landed at Arcata at night in aircraft without landing lights thought the light arrangement was excellent. The added lights were turned out at times in order to determine the pilots' reactions, and some pilots requested that these lights be turned on again. Those pilots who were thoroughly familiar with the arrangement of the field and who had landing lights on their aircraft thought the additional lights were helpful but not necessary. Observations from a surface vehicle indicated that the spacing used was adequate for this particular section of taxiway.

The use of double lights spaced five feet apart perpendicular to the runway for marking runway exits seemed to be of no special benefit and might actually make the determination of the outline of the taxiway more difficult. The extra lights at these positions could be used better for closer spacing of the lights along the curves.

3.4.2.4 Summary of Arcata Field Tests. None of the configurations tested at Arcata Airport was a solution to the general problem, but closer spacing of the exit taxiways was found to be useful. The work was terminated with no formal summary report being prepared. Details of the work are reported in the Progress Reports of the period [31].

3.5 Exit Centerline Lights and Marks

3.5.1 Extended Taxiway Centerline Markings

Taxiway centerline marks extending onto the runway and curved to meet the runway centerline markings (figure 2) were introduced early in the development of taxiway markings and has continued to the present [7]. These markings locate the exit and provide guidance during the turn off the runway by day except under visibility conditions so low that centerline lights are required for guidance to aircraft on the taxiways.

The guidance these markings provide at night is uncertain as retroreflective markings are not required, and markings of ordinary paint can disappear under some conditions of runway wetness. The effectiveness of these markings would be significantly improved were they made of a high-efficiency retroreflective material. Retroreflective markings would not, however, be effective at night under conditions of very low visibility.

Centerline markings are used on both low-speed and high-speed exits [17a]. No indication of confusion between the two types of exits resulting from the marks was found in the search of the literature.

At the time curved centerline markings were considered as a National Standard (circa 1950), tests of modifications of these markings designed to give the pilot advance information as to the position of exits during rollout were made at the Naval Air Test Center [33]. The markings extended 500 feet ahead of the exits and had diagonal stripes or "feathers" projecting from the extended centerline marking on the side of the exit. The conclusions reached were that: a) the marking should extend along the runway centerline a distance of 1000 feet; b) the "feathers" were ineffective as indicators of the distance to the exit; and c) further work was required. However, the markings shown in figure 2 were adopted as a National Standard [7] and have been unchanged for 25 years [34].

3.5.2 Extended Taxiway Centerline Lights

3.5.2.1 Early Development. As stated in Section 1.2.2, the use of taxiway centerline lights extended onto the runway and curved to meet the runway centerline (figure 4a), was installed at Heathrow Airport at the time of its conversion to a civil airport, circa 1950, and use of this configuration spread rapidly in Europe.

3.5.2.2 Deliberations of Visual Aids Panel. The Visual Aids Panel has given extensive consideration to numerous proposals for identifying exit taxiways including the use of centerline lights over the years.

Taxiway lighting and marking was put on the agenda of the Visual Aids Panel (VAP) at its First Meeting in 1960 [35].

At its Second Meeting (1962) the VAP considered the problem of differentiating between low-speed and high-speed exits [36]. After discussion of several alternatives, one member stated that the use for low-speed exits of green lights on the extension of the taxiway centerline on the runway had been found very satisfactory for service on low-speed exits and in this form there could be no possible confusion with the lights indicating a high-speed exit, provided the lights marking the low-speed exit did not parallel the runway centerline to an appreciable extent. White was considered the best color for the lights marking a high-speed exit because of the greater visual range of white lights. Amendments to Annex 14 were drafted at the Seventh Meeting of the AGA Division, held later in 1962, providing for the use of green centerline lights for low-speed exits and white for high-speed exits [18].

In 1964, at its Third Meeting [37], the VAP reconsidered its choice of white lights for high-speed exits because of an incident which resulted when the pilot of

an aircraft which had been displaced 30 feet from the centerline of the runway during visual aids evaluation trials, had mistaken the runway exit taxiway lighting for the runway centerline in a simulated very low visibility condition and at high speed. The Panel exchanged views changing the colour of high-speed exit taxiway centerline lighting to green. Green lights were used for standard exit taxiways and some members thought there was a need to distinguish the types of exits, though it was recognized that taxiways were not presently entered at the higher speeds particularly in low visibility conditions. It was agreed that it was premature to amend Annex 14 and that further tests were required. After considerable discussion of several alternatives, the VAP concluded that the only existing means of providing good visual exit guidance to taxiways was by means of taxiway centerline lighting extended onto the runway whether or not runway centerline or taxiway centerline lighting was installed. It was therefore decided to recommend an amendment to Annex 14 to emphasize the need for centerline exit lighting and specifying that the lighting continue from the runway centerline to a point at least 100 feet from the edge of the runway as follows:

"PART V, Chapter 2 - Taxiway lighting"

Add the following to the end of para. 2.11.3

"At other exit taxiways serving runways with a high utilization at night, guidance should also be provided by means of taxiway centerline lighting irrespective of whether or not runway centerline lights or other taxiway centerline lights are provided."

After para. 2.11.6, add the following:

"2.11.6/1 Recommendation. Where provided, lighting for an exit to a taxiway other than that specified in 2.11.6 should commence near the runway centerline and continue to a point on the centerline of the taxiway, at least 30m (100 ft) from the edge of the runway."

Note that such details as radius of curvature of the lights onto the runway and the color of the lights and possible advance warning of the exit, not specified. Study of this problem continued.

In 1966, at its Fourth Meeting, the VAP agreed that the color of the lights on high-speed exits should be changed to green, as tests of other methods of differenti-

ating high speed exit lights from runway centerline had not produced a suitable alternative. A Working Group was established to coordinate a study of further development of runway centerline coding, runway end lighting, and exit taxiway lighting. As these aids were interrelated, it was necessary that changes in their patterns or colors be studied simultaneously [38].

In 1970, at its Fifth Meeting, the VAP, considering the findings of the Working Group, resolved its difficulties with specifications for centerline lighting of low-speed exits [39]. Experiments to improve exit taxiway identification by installing double yellow lights at exit taxiways and by installing green lights in the runway centerline lighting had been tried. The double yellow lights tended to be confused with runway edge lights at low intensity settings and the green light in the runway centerline reduced centerline guidance. Flashing lights had also been tried with poor results. The VAP considered that the only practical method was the extension of taxiway centerline lighting onto the runway. The VAP had deferred development of exit taxiway lighting for right angled exits at its previous meetings as there was concern that these lights might be confused with runway end lights. Now that runway end lights were being changed to red and experience had indicated that there was no problem of confusion with high-speed exit taxiways, it was agreed to propose inclusion of specifications for these exits in Annex 14. Both right angle and curving patterns were considered and it was agreed to have the exit lights follow the curved portion of the exit taxiway centerline marking on the runway.

This concluded the work of the VAP on the configuration and color requirements for exit taxiways. Later work on taxiway lighting consisted of upgrading of requirements and the modifications of spacing and intensity distribution requirements to provide guidance in Category III weather conditions [40a, 40b].

3.5.2.3 Studies in the United States. During the period in which the VAP was studying the lighting of exit taxiways, the United States conducted several evaluations of exit lighting.

Tests of green centerline lights installed on large radius exits at Dulles International Airport and at NAFEC showed that the green exit lights would not be confused with the white, runway centerline lights [41].

Green retroreflective centerline taxiway delineators were installed at Washington National Airport and at NAFEC extending from the "throat" of two taxiways along curves to the points of tangency with the runway centerline. The results of these tests were favorable. Some pilots desired an imminence signal ahead of the intersection [42].

An extensive evaluation of taxiway centerline lights was made at NAFEC following the studies reported above. This study included tests to determine the suitability of using green lights on a curved extension of the taxiway centerline to the runway centerline. It was concluded that green lights or retroreflectors could be used in the surface of the runway for exit purposes on short radius curves [28].

3.5.3 Current Status of Exit Taxiway Lighting

As a result of the findings of the Visual Aids Panel, provision for taxiway centerline lights extended onto the runway at low-speed exits is now an ICAO Standard for taxiways intended for use at night in Category III runway visual range conditions and an ICAO Annex 14 Recommended Practice for other runway visual range conditions [18]. The provisions for the lighting of taxiways, including exit taxiways at Navy airfields, are in accord with the ICAO provisions given above [15]. The Air Force is using no centerline lights on taxiways and exit taxiways [43].

Even though all data obtained by NAFEC during its extensive series of tests of green exit lights installed on the runway, some of which extended over a considerable period of time to permit exposure to industry, U.S. civil standards do not provide for the use of these low-speed exit centerline lights. There is still considerable concern about the possibility of confusion with the green exit lights on high-speed exits [44]. A simulator study designed to test the validity of this concern would be very helpful.

There are also methods of reducing the possibility of confusion. Among these are the following:

a. The use of blue, instead of green, for lights installed on the surface of the runway to mark low-speed exits.

b. Extending the exit lights of low-speed exits only a short distance onto the runway.

c. Instead of curving the row of lights on low-speed exits to meet the runway centerline, extending the lights to the runway centerline in a straight line.

d. Use of pulsating, or sequentially flashed, low-speed exit centerline lights.

e. Use of a lateral barette of green lights at the intersection of the taxiway centerline with the runway centerline in combination with b for low-speed exits.

f. Extending the exit lights of low-speed exits on a curve that becomes parallel to runway centerline at 15 to 20 feet from runway centerline.

3.6 Use of Flashing Identification Lights

3.6.1 Early Studies

Flashing lights have long been used as signals in all forms of transportation [45]. One of the reasons for this is their conspicuity. For example, Crawford has shown that when a signal is presented against a background of steady-burning lights the response time of the observer to a flashing signal was less than if the signal were steady, that it had greater attention-drawing power [46]. It is, therefore, no surprise that flashing lights have been considered as a means of identifying exit taxiways on numerous occasions.

A flashing blue light was installed on the runway centerline 500 feet before the point of tangency of the lights marking a high-speed turn off at Indianapolis in 1958 [47]. (No report of the results of tests of this installation were found.)

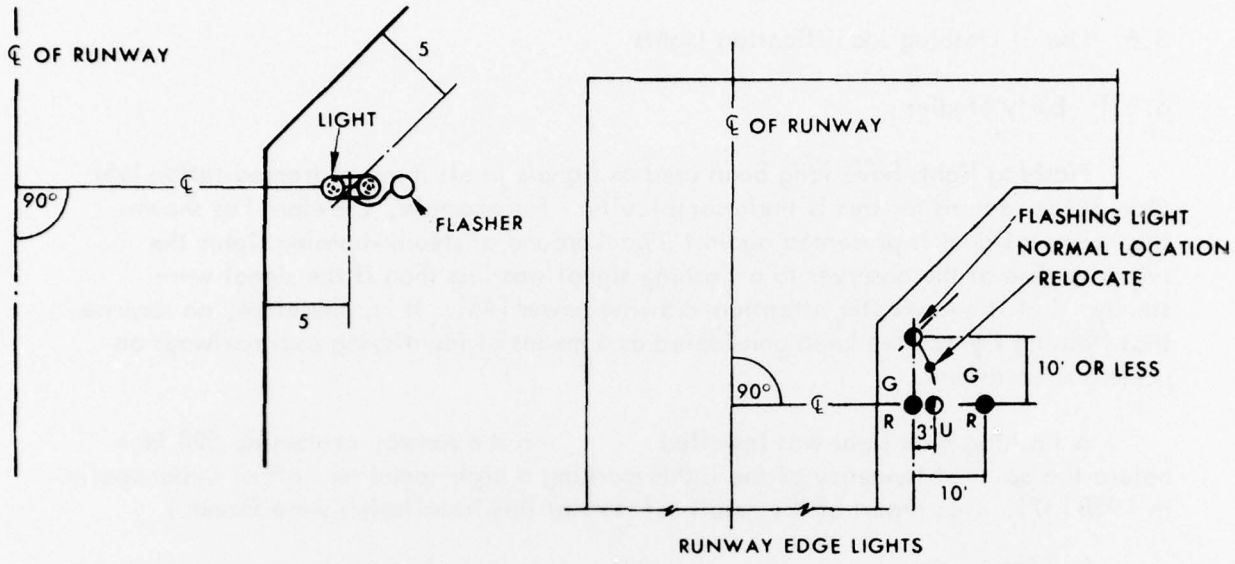
In 1959, Lybrand, Vaughan, and Robinson recommended their use after reviewing developments in airport marking and lighting during the previous decade [48]. Flashing lights on the centerline of high-speed exits were tested in France and in the United Kingdom [49]. Flashing yellow lights to mark the exit throat have also been tried [50, 51]. Flashing of runway edge lights adjacent to the exit throat has also been tested. None of these methods was found to be useful [40].

Throughout its existence, the VAP has been concerned with the proliferation of flashing lights on the movement area of airports. Some members believed that Annex 14 should be amended to prohibit all such usage stating that use of flashing lights on the movement area should be limited to aircraft, emergency, and service vehicles. Others believed that there might be situations for which flashing lights could be used to good advantage but that the usage should be kept to a minimum [36, 51, 52]. The concern of the VAP is supported by the laboratory studies of Crawford, who found that the presence of only one irrelevant flashing light in the background decreased the effectiveness of a flashing signal significantly [46, 53].

3.6.2 The Canadian System

The Canadian Department of National Defence has recently developed a system of flashing lights for marking exit taxiways which overcomes most of the objections raised in the past. No formal reports describing the system or the results of the test are available. The following description is based upon telephone conversations and the installation drawing shown in figure 11 [54, 55].

The system consists of a pair of blue lights mounted in line with the runway edge lights at the beginning of the exit throat. The lights flash alternately in a



NOTE

A TAXIWAY TURNOFF LIGHT WHOSE NORMAL LOCATION IS LESS THAN 10 FEET FROM A RUNWAY LIGHT SHALL BE RELOCATED AS SHOWN IN DETAIL A

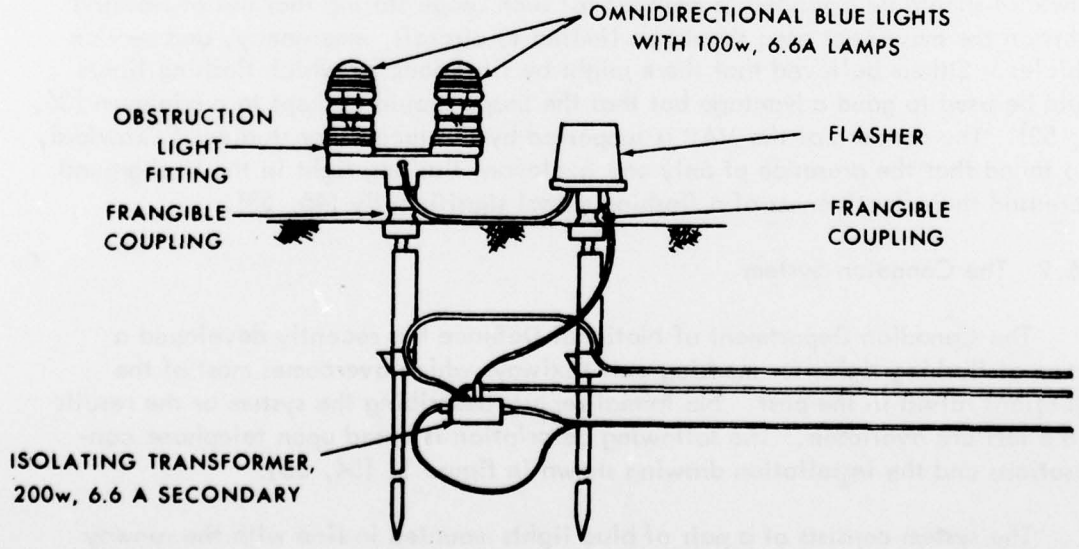


Figure 11: - Installation Drawing of Canadian System of Flashing Blue Lights. (Extracted from reference 55.)

wig-wag manner. The lights are closely spaced and are seen as a single source at distances greater than 1000 to 2000 feet. The intensity of each light during a cycle varies from 100% to 25% of full intensity. Thus, the sum of the intensities of the two lamps is sufficiently constant to cause the lights to appear as a steady source at distances in excess of about 2000 feet, thereby reducing the number of flashing lights in the pilots field of view, and, as approached, the lights produce a conspicuous wig-wag signal.

The lights flash with a frequency of 90 cycles per minute. A rate of 60 cycles per minute was found to be too slow to be conspicuous, and a rate of 120 cycles per mintes did not allow the lights to reach full intensity during their ON period. Only the exit lights on active runways are flashed.

To provide additional guidance, the extended taxiway centerline marking is made of a high-efficiency retroreflectorized tape and a retroreflectorized exit sign or arrow is installed at the far side of the exit throat.

The Canadian Department of Defence has found that the system works very well, particularly in foggy weather, and that the system has speeded-up traffic. However, the system is not being used by the Canadian Department of Transport.

It is apparent that the system needs careful study, first of the concept and then, if the system is found useful, of such design parameters as intensity, intensity distribution, flash rate, light location, and light spacing.

4. SUMMARY

The problem of lighting exit taxiways has been a long standing one. Many methods to solve this problem have been proposed, tested, and found wanting.

The problem is more than that of marking the location of the exit. Guidance during the turn from the runway into the exit taxiway must be provided also.

The use of green lights installed in the surface of the runway on the extended taxiway centerline marking is the only method which has received general acceptance, is in wide spread use, and provision for such usage has been made by ICAO.

Centerline lights are not used to mark low speed exits at U.S. civil airports because of concern over the possible confusion of a low-speed exit for a high-speed exit. A study is required to determine the validity of this concern. In addition, studies of modifications of the design of the configuration now used elsewhere for low-speed exit lighting are required to develop a modification which would reduce the possibility, if any, of confusion and at the same time provide adequate turn-off guidance.

A system of flashing blue exit lights developed by the Canadian Department of National Defence meets most of the objections raised in the past over the use of flashing lights to mark fixed points on the movement area of airports. The system has been found satisfactory by its developers and is now in service.

The type L-829 is not adequately conspicuous. The conspicuity of such signs on runway exits could be increased by removing the panels forming the letters of the legends of these signs, thereby exposing the illuminated background panels.

The present omni-directional lights emit light in directions in which it is not required even if these lights are shielded. Improved shielding and brightness control of these lights would reduce the sea-of-blue effect significantly, as would sectionalizing the taxiway lighting system so that only the lights on taxiways serving the duty runway would be lighted.

5. RECOMMENDATIONS

The recommendations listed below are based upon the analysis of the literature cited in this report and summarized in Section 4.

It is recommended that:

1. The system of flashing blue exit lights developed by the Canadian Department of Defence be tested to determine: a) the operational benefits obtained from the system; and b) if these lights are found to be useful, of the values of such design parameters as flash rate, light separation, and intensity. A study should also be made of the value of these lights when used in conjunction with low intensity exit centerline lights.

2. A study be made to determine if the concern regarding the possibility of confusing low-speed exit centerline lights with high-speed centerline lights is valid.

3. A study be made of the effectiveness of such methods of reducing the confusion between low-speed and high-speed exit lights as the use of blue instead of green lights, reducing the length of the extension of the exit lights on the runway, and of using very low intensity exit centerline lights in conjunction with the flashing blue lights used by the Canadian Department of Defence.

4. A study be made of the desirability of increasing the conspicuity of Type L-829 signs marking runway exits by removing their letter-forming panels.

5. The shielding of taxiway edge lights be improved.

6. Asymmetric lenses be used on taxiway edge lights wherever feasible.

7. Intensity control be provided for taxiway edge lights.

8. High-efficiency retroreflective material be used for the exit taxiway markings.

9. Systems of taxiway centerline lights and retroreflective edge markers be used instead of edge lights wherever feasible.

10. When edge light systems are used, sectionalizing of circuits be provided and only those sections of taxiways serving the duty runway(s) be lighted.

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